# СИСТЕМНИЙ АНАЛІЗ І ТЕОРІЯ ПРИЙНЯТТЯ РІШЕНЬ

# СИСТЕМНЫЙ АНАЛИЗ И ТЕОРИЯ ПРИНЯТИЯ РЕШЕНИЙ

# SYSTEM ANALYSIS AND DECISION-MAKING THEORY

UDC 519.2 **DOI: 10.20998/2079-0023.2019.02.01**

*A. E. GOLOSKOKOV, A. A. YAKOVENKO*

## ASSESSMENT OF THE COMPLEX SYSTEM CONDITION (ON THE EXAMPLE OF AN IT COMPANY)

The paper considers the problem of estimating the state of the enterprise (on example of the IT company). The problem is presented in the form of two problems. The first problem is the aggregation of the initial information and the second problem is the identification of the state of a complex system. Authors formulated the problem and selected methods for solution of the problem. It is possible to form software for solving research problems. To solve the problem of aggregation of initial data authors used the fuzzy cluster analysis, namely the fuzzy *k*-means method. A numerical research was carried out and a test case was figured out in the MATLAB environment. In this test case the source data was reduced to a dimensionless form. Thereafter, already reduced to the same scale, the initial attributes were reduced to fuzziness. The results allow to formalize linguistic variables, which are characterized by the term-sets and definition range. The numerical results were approximated by analytical membership functions. The solution of the first task allows to generate a set of possible fuzzy reference situations, which reflect the possible state of the system. Each situation is characterized by the reference informational granule, which contains information about formalized linguistic variables. The second problem was solved by using the method of fuzzy logic in the MATLAB environment. The test case was calculated. In this test case, the search of the situation in which the IT-company is located was performed. At this stage, the current situation belongs to comparison with each reference situation. In this way, authors determined the most similar reference situation to the current situation. An analysis of the resulting situation allows to argue the state of the IT company. The solution of the second task allowed to establish assessment of IT company state. The theoretical and practical results can improve the efficiency of complex system management.

**Keywords:** complex system management, condition assessment, fuzzy cluster analysis, situational approach, reference situations, informational granule.

*О. Є. ГОЛОСКОКОВ, А. А. ЯКОВЕНКО*

## ОЦІНКА СТАНУ СКЛАДНИХ СИСТЕМ (НА ПРИКЛАДІ IT-КОМПАНІЇ)

У роботі розглянута проблема оцінки стану підприємства (на прикладі IT-компанії). Проблема представлена у вигляді двох задач, а саме: агрегування вихідної інформації і ідентифікація стану складної системи. Сформульовано постановки задачі та обрані методи їх вирішення. Це дозволило сформувати математичне забезпечення для вирішення задачі дослідження. Для вирішення задачі агрегування вхідних даних використаний нечіткий кластерний аналіз, а саме нечіткий метод K-середніх. Здійснено числові дослідження та прорахований тестовий приклад в середовищі MATLAB. В рамках даного тестового прикладу здійснено приведення вхідних даних до безрозмірного вигляду. Після цього, вже приведені до єдиної шкали, вхідні ознаки були приведені до нечіткості в результаті чого вдалося формалізувати лінгвістичні змінні, які характеризуються терм-множинами і областями визначення. Отриманий чисельний результат був апроксимований аналітичними функціями належності. Вирішення першого завдання дозволило сформувати множину можливих нечітких еталонних ситуацій, що відображають можливі стани системи. Кожна еталонна ситуація характеризується інформаційної гранулою, яка містить інформацію про формалізовані лінгвістичні змінні. Друга задача була вирішена за допомогою методу нечіткої логіки в середовищі MATLAB. Прорахований тестовий приклад, який полягає в пошуку ситуації, в якій знаходиться IT-компанія. На даному етапі поточна ситуація підлягає порівнянню з кожною еталонною ситуацією, в результаті чого визначається найбільш схожа ситуація до поточної. В результаті аналізу отриманої ситуації здійснюється аргументування стану IT-компанії. Вирішення другої задачі дозволило встановити оцінку стану IT-компанії. Отримані теоретичні та практичні результати дозволяють підвищити ефективність процесу управління складною системою.

**Ключові слова:** управління складною системою, оцінка стану об'єкту, нечіткий кластерний аналіз, нечіткий ситуаційний підхід, еталонні ситуації, інформаційна гранула.

*А. Е. ГОЛОСКОКОВ, А. А. ЯКОВЕНКО*

## ОЦЕНКА СОСТОЯНИЯ СЛОЖНЫХ СИСТЕМ (НА ПРИМЕРЕ IT-КОМПАНИИ)

В работе рассмотрена проблема оценки состояния предприятия (на примере IT-компании). Проблема представлена в виде двух задач, а именно: агрегирование исходной информации и идентификация состояния сложной системы. Сформулированы постановки задач и выбраны методы их решения. Это позволило сформировать математическое обеспечение для решения задачи исследования. Для решения задачи агрегирования исходных данных использован нечеткий кластерный анализ, а именно нечеткий метод K-средних. Осуществлены численные исследования и просчитан тестовый пример в среде MATLAB. В рамках данного тестового примера осуществлено приведение исходных данных к безразмерному виду. После этого, уже приведенные к единой шкале, исходные признаки были приведены к нечеткости в результате чего удалось формализовать лингвистические переменные, которые характеризуются, терм-множествами и областями определения. Полученный численный результат был аппроксимирован аналитическими функциями принадлежности. Решение первой задачи позволило сформировать множество возможных нечетких эталонных ситуаций, отображающих возможные состояния системы. Каждая эталонная ситуация характеризуется информационной гранулой, которая содержит информацию о формализованных лингвистических переменных. Вторая задача была решена с помощью метода нечеткой логики в среде MATLAB. Просчитан тестовый пример, который заключается в поиске ситуации, в которой находится IT-компания. На данном этапе текущая ситуация подлежит сравнению с каждой эталонной ситуацией, в результате чего определяется наиболее схожая ситуация к текущей. В результате анализа полученной ситуации осуществляется аргументирование состояния IT-компании. Решение второй задачи позволило установить оценку состояния IT-компании. Полученные теоретические и практические результаты позволяют повысить эффективность процесса управления сложной системой.

**Ключевые слова:** управление сложной системой, оценка состояния объекта, нечёткий кластерный анализ, нечёткий ситуационный подход, эталонные ситуации, информационная гранула.

**Introduction.** The problem of managing complex objects is one of the actual problems. It is characterized by a large amount of information, a set of contradictory criteria, a poor formalizability, and the influence of random environmental factors. This leads to necessity to use the mathematical apparatus of fuzzy situational control.

The main function of the system management is to develop control actions to actuating mechanism in accordance with a set of rules. A necessary condition for the correctness of the generated effects is a reliable assessment of the current state in which the control object is located.

This article discusses the aggregation of source data and the procedure for assessing the state of an object.

**Description of the research object.** The Authors have decided to consider the IT company as a research object. An IT company develops custom software for foreign companies. The company operates according to the B2B model (business to business), it means, that a company produces services and products not for the end consumer, but for other business companies. The set of services that are offered by developers is development, testing, maintenance and support of software and business applications, creation of dedicated centers for development, testing and quality control of software and IT consulting, taking into account the specifics of the business sector (finance, insurance, medicine, biotechnology, energy).

**Formulation of the problem.** The formulation of the problem has been considered from the point of view of situational control in a fuzzy environment.

The state of the control object can be assessed by the values of attributes - the distinctive features of the object. The power of a set of attributes is determined by the objectives of the control object and the features of the control system.

The set of attributes values that describes the state of the control object and the environment at some point in time is called a situation. It is important to notice, that in the progress of describing the attributes values, a large number of situations may be formed. In this case, it is necessary to aggregate the information.

The set of reference situations adequately describes the possible states of the object, provided that the management features are taken into account. However, it is impossible to take into account all the features of management. This leads to the need to use the concept of a fuzzy situation [11].

A formal definition of “fuzzy situation” have been given. Let $Y$ be a stet of attributes, whose values describe the state of the control object. Each sign $Y_i$ is described by a linguistic variable $< Y_i, T_i, D_i >$, where $T_i = \{T_{1i}, \dots, T_{mi}\}$ – term-set of linguistic variable $Y_i$, $mi$ – is the number of values of the attribute, $D_i$ – is the base set of the attribute $Y_i$. The number of possible situations in the enterprise is very large, and the number of management decisions made is much smaller. If the set of complete situations is divided into subsets, each of which can be assigned a single typical solution, then the management task, roughly speaking, will be reduced only to the classification of external situations entering the system. Thus, the problem of identification can be represented in the form of two tasks. Namely, the aggregation of the initial information and assessment of the state of the IT-company.

The purpose of this work is to increase the efficiency of the process of assessing the state of a poorly formalized complex system. The article solves the following tasks: aggregation of source data; assessment of the state of a complex system [12].

**Data aggregation.** By aggregating information, the authors understand the concentration of individual information flows into an information granule of a single integrated aggregate, which makes it possible to get a general picture of the situation in the system. An informational granule is a linguistic variable. The formation of informational granules was carried out using the method of fuzzy cluster analysis, namely the fuzzy *k*-means method [1].

**Data rationing.** The input attributes $x_1$ and $x_2$ have different dimensions. In order to be able to compare these attributes, it is important to bring them to a dimensionless form. Thus, the intervals considered should be brought to a single scale. The reduction to a single scale is provided by the normalization of each variable over the range of variation of its values. The authors considered 2 methods of bringing the source data to a single scale, which normalize the bulk of the data at the same time guaranteeing that the value is located in the range [0;1]:

Linear rationing. This method of data rationing is one of the most common. The value of each element is determined by the formula (1) [7].

$$x_i^* = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}, \qquad (1)$$

where $x_i$ – element value;

$x_{\min}$ – minimal range value;

$x_{\max}$ – maximum range value.

Linear normalization is optimal when the variable values tightly and uniformly fills the interval defined by the empirical scale of the data. But this approach is not always applicable. So, if there are relatively rare outliers in the data, which far exceed the typical variation, then this will lead to the fact that the majority of the values of the normalized variable will concentrate near zero.

Sigmatic rationing. In connection with the shortcomings of the first method, it is safer to orientate, when normalizing, not typical extremes, but typical one’s statistical characteristics of the data, such as mean and variance. Sigmatic rationing allows to find a natural way out of this situation and at the same time all the values $x_i \in [0; 1]$ [7].

Sigmatic rationing is carried out according to the formula (2).

$$x_i^* = f\left(\frac{x_i - \overline{x}}{\sigma}\right), \quad (2)$$

where $\overline{x} = \frac{\sum_1^n x_i}{n}$; $\sigma = \sqrt{\frac{\sum_1^n (x_i - \overline{x})^2}{n}}$; $f(a) = \frac{1}{1+\exp(-a)}$.

**Data clustering.** The state of the object or subject area can be characterized by the values of some attributes or parameters. If the set of states of an object has common properties, or the values of attributes of the description of states, it means that there is a class of object states. Under the procedure of the formation of classes, classification, understand the ordering of the states of the object according to their similarities. The fuzzy $k$-means method creates groups from a set of objects so that the group members are the most homogeneous. The authors decided to use the fuzzy $k$-means method to form term sets of linguistic variables. In the work was used a package Matlab [10].

Suppose that the attribute $x_1$ takes values on the interval [1; 15]. Having carried out the normalization of this attribute, appears an opportunity to represent the elements of the set in the range [0; 1]. The resulting elements are subject to clustering, as a result, all the elements are divided into 3 groups, each of which corresponds to a specific cluster. The established cluster centers using the Matlab package are listed in Table 1.

Table 1 – Cluster centers of attribute $x_1$

| Cluster | Center |
|---|---|
| 1 | 0.2528 |
| 2 | 0.5014 |
| 3 | 0.7582 |

The values of the membership function are given in the table. 2

Table 2 – Matrix of belonging of elements $x_1$ to each of the clusters

| Element | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| 1 | 0.9343 | 0.0034 | 0.0035 |
| 2 | 0.9734 | 0.0113 | 0.0203 |
| 3 | 0.9998 | 0.0209 | 0.0692 |
| 4 | 0.9102 | 0.2301 | 0.0423 |
| 5 | 0.7426 | 0.6340 | 0.0029 |
| 6 | 0.6144 | 0.7132 | 0.1142 |
| 7 | 0.4092 | 0.9614 | 0.2255 |
| 8 | 0.3321 | 0.9746 | 0.3374 |
| 9 | 0.2221 | 0.7746 | 0.4232 |
| 10 | 0.1134 | 0.5943 | 0.5692 |
| 11 | 0.0021 | 0.5134 | 0.6152 |
| 12 | 0.0423 | 0.0342 | 0.7477 |
| 13 | 0.0642 | 0.0023 | 0.9723 |
| 14 | 0.0203 | 0.0051 | 0.9909 |
| 15 | 0.0034 | 0.5234 | 0.9596 |

Each row of this matrix describes the degree of belonging of all elements to one of three clusters.

Similarly, terms for the attribute $x_2$ were formed. The definition range of this attribute is characterized by an interval [10; 20]. As a result of clustering, the following cluster centers were obtained (table 3):

Table 3 – Cluster centers of attribute $x_1$

| Cluster | Center |
|---|---|
| 1 | 0.2528 |
| 2 | 0.5014 |
| 3 | 0.7582 |

The values of the membership function are given in the table 4.

Table 4 – Matrix of belonging of elements $x_1$ to each of the clusters

| Element | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| 10 | 0.9343 | 0.0034 | 0.0035 |
| 11 | 0.9734 | 0.0113 | 0.0203 |
| 12 | 0.9998 | 0.0209 | 0.0692 |
| 13 | 0.9102 | 0.2301 | 0.0423 |
| 14 | 0.7426 | 0.6340 | 0.0029 |
| 15 | 0.6144 | 0.7132 | 0.1142 |
| 16 | 0.4092 | 0.9614 | 0.2255 |
| 17 | 0.3321 | 0.9746 | 0.3374 |
| 18 | 0.2221 | 0.7746 | 0.4232 |
| 19 | 0.1134 | 0.5943 | 0.5692 |
| 20 | 0.0021 | 0.5134 | 0.6152 |

In order to use the membership functions, they need to be approximated. In this situation, the authors used the Matlab package. The results of the approximation are shown in table 5 [8].

**Formulation of the problem.** On the basis of the obtained results, the set of reference situations have been formed, which is characterized by a set of attributes $X = \{x_1, x_2\}$.

The set of reference situations is a combination of all possible variants of certain terms of these signs. As a result, 9 reference situations were formed [3].

$S_1 =$ << ”Number of projects in development” / “few” > / $x_1$ >, << ”Amount of developers involved”, / “few” > / $x_2$ >;

$S_2 =$ << ”Number of projects in development” / “few” > / $x_1$ >, << ”Amount of developers involved”, / “enough” > / $x_2$ >;

$S_3 =$ << ”Number of projects in development” / “few” > / $x_1$ >, << ”Amount of developers involved”, / “many” > / $x_2$ >;

$S_4 =$ << ”Number of projects in development” / “enough” > / $x_1$ >, << ”Amount of developers involved”, / “few” > / $x_2$ >;

$S_5 =$ << ”Number of projects in development” / “enough” > / $x_1$ >, << ”Amount of developers involved”, / “enough” > / $x_2$ >;

$S_6 =$ << ”Number of projects in development” / “enough” > / $x_1$ >, << ”Amount of developers involved”, / “many” > / $x_2$ >;

$S_7 =$ << ”Number of projects in development” / “many” > / $x_1$ >, << ”Amount of developers involved”, / “few” > / $x_2$ >;

Table 5 – Approximte membership functions

| Attribute | Term | Membership function |
|---|---|---|
| $x_1$ | Few | $\mu_1(x_1) = 0{,}5557\exp\left\{-\left(\frac{(x_1-0{,}3137)^2}{0{,}08963}\right)\right\} + 0{,}5557\exp\left\{-\left(\frac{(x_1-0{,}3137)^2}{0{,}08963}\right)\right\}$ |
| | Enough | $\mu_2(x_1) = 82.1\exp\left\{-\left(\frac{(x_1-0{,}5008)^2}{0{,}1025}\right)\right\} - 81{,}11\exp\left\{-\left(\frac{(x_1-0{,}5008)^2}{0{,}102}\right)\right\}$ |
| | Many | $\mu_3(x_1) = 0.5568\exp\left\{-\left(\frac{(x_1-0{,}6877)^2}{0{,}08898}\right)\right\} + 0{,}901\exp\left\{-\left(\frac{(x_1-0{,}8256)^2}{0{,}1327}\right)\right\}$ |
| $x_2$ | Few | $\mu_1(x_1) = 0.4595\exp\left\{-\left(\frac{(x_1-0{,}288)^2}{0{,}08343}\right)\right\} + 0{,}8856\exp\left\{-\left(\frac{(x_1-0{,}1608)^2}{0{,}1518}\right)\right\}$ |
| | Enough | $\mu_2(x_1) = -759.2\exp\left\{-\left(\frac{(x_1-0{,}5009)^2}{0{,}1022}\right)\right\} - 760{,}2\exp\left\{-\left(\frac{(x_1-0{,}5009)^2}{0{,}1023}\right)\right\}$ |
| | Many | $\mu_3(x_1) = -12.79\exp\left\{-\left(\frac{(x_1-0{,}6927)^2}{0{,}07384}\right)\right\} + 13{,}32\exp\left\{-\left(\frac{(x_1-0{,}6927)^2}{0{,}07452}\right)\right\}$ |

$S_8 =$ << ”Number of projects in development” / “many” > / $x_1$ >, << ”Amount of developers involved”, / “enough” > / $x_2$ >;

$S_9 =$ << ”Number of projects in development” / “many” > / $x_1$ >, << ”Amount of developers involved”, / “many” > / $x_2$ >;

Each reference situation characterizes a certain state of an IT company. They can be formalized to argue the state of the company. For comparison, two situations $S_1$ and $S_9$ were considered [4].

So, the situation $S_1$ displays the reference state of an IT company, which means that the company performs few projects and at the same time few professionals are loaded. This condition is ineffective.

Situation $S_9$ displays the state of the company, which means that the company has a large number of orders and many experts are involved. This condition is effective.

The reference state of the system is characterized by a fuzzy information granule. The aggregation of the initial data significantly reduced the dimension of the research problem [2].

**Assessment of the current state of the IT company.** A test example was considered, on the basis of which the company is currently developing 5 projects in which 25 developers are involved.

The initial attributes are heterogeneous, and their estimates for the parameters are not consistent. Considering the attribute $x_1$, rationing of the definition range [1; 15] was carried out using linear and sigmatic rationing according to the formulas (1) and (2), respectively. The results of the calculations are presented in table 6.

Table 6 – Results of rationing of attribute $x_1$

| $x$ | first method | second method |
|---|---|---|
| 1 | 0 | 0.165 |
| 2 | 0.071 | 0.199 |
| 3 | 0.142 | 0.239 |
| 4 | 0.214 | 0.299 |
| 5 | 0.285 | 0.343 |
| 6 | 0.357 | 0.394 |
| 7 | 0.428 | 0.442 |
| 8 | 0.5 | 0.5 |

End of table 6 – Results of rationing of attribute $x_1$

| $x$ | First method | Second method |
|---|---|---|
| 9 | 0.571 | 0.549 |
| 10 | 0.642 | 0.601 |
| 11 | 0.714 | 0.684 |
| 12 | 0.785 | 0.703 |
| 13 | 0.857 | 0.76 |
| 14 | 0.928 | 0.8 |
| 15 | 1 | 0.834 |

Next, it is necessary to determine the degree of fuzziness of each fuzzy set. For this have been made a clustering of data, obtained as a result of rationing was carried out (Table 6). To determine the degree of fuzziness, two sets were considered, that determine the belonging of elements to the term set “few”. The obtained results were approximated by analytical membership functions and the values of these functions were determined on the interval [0;1] with a step $h = 0.1$ . The results presented in Table 7.

Table 7 – Membership functions values of fuzzy sets

| $x$ | $L_1 = \mu_{A_1}$ | $L_2 = \mu_{A_2}$ |
|---|---|---|
| 0.1 | 0.9061 | 0.172 |
| 0.2 | 0.983 | 0.672 |
| 0.3 | 0.953 | 0.98 |
| 0.4 | 0.555 | 0.912 |
| 0.5 | 0.123 | 0.257 |
| 0.6 | 0.009 | 0.008 |
| 0.7 | 0.0003 | 0.0001 |
| 0.8 | 0 | 0 |
| 0.9 | 0 | 0 |
| 1 | 0 | 0 |

This way two fuzzy sets were obtained $L_1 = \mu_{A_1}$ and $L_2 = \mu_{A_2}$. On the basis of fuzzy sets, clear sets $\overline{L_1} = \overline{\mu_{A_1}}$ and $\overline{L_2} = \overline{\mu_{A_2}}$ were constructed, which are the closest to the considered fuzzy sets. The construction of the clear set is carried out according to the formula (3).

$$L_{i_{k,j}} = \begin{cases} 1, & \text{if } \quad L_{k,j} > 0.5 \\ 0, & \text{if } \quad L_{k,j} \le 0.5 \end{cases} \tag{3}$$

As a result of the calculations, clear sets $\overline{L_1} = \overline{\mu_{A_1}}$ and $\overline{L_2} = \overline{\mu_{A_2}}$ were obtained. These sets are presented in table 8.

Table 8 – Membership functions values of clear sets

| $x$ | $\overline{L_1} = \overline{\mu_{A_1}}$ | $\overline{L_2} = \overline{\mu_{A_2}}$ |
|---|---|---|
| 0.1 | 1 | 0 |
| 0.2 | 1 | 1 |
| 0.3 | 1 | 1 |
| 0.4 | 1 | 1 |
| 0.5 | 0 | 0 |
| 0.6 | 0 | 0 |
| 0.7 | 0 | 0 |
| 0.8 | 0 | 0 |
| 0.9 | 0 | 0 |
| 1 | 0 | 0 |

Now when clear sets are built, it is possible to calculate the indices of fuzziness of each set. To determine the indices of fuzziness, it was decided to use the Euclidean distance using the formula (4).

$$I^E = \frac{2}{\sqrt{n}} \sum_{i=1}^{n} \sqrt{\mu_A(x_i) - \overline{\mu_A}(x_i)}. \tag{4}$$

To calculate the fuzziness of the sets, the office suite Microsoft Excel was used. As a result, the following fuzziness values were obtained:

$$I_1^E = 0.2855,$$

$$I_1^E = 0.277$$

Now, it is possible to make a conclusion that a fuzzy set obtained as a result of applying sigmatic data normalization is less fuzzy. So, using the sigmatic method, a less fuzzy set was obtained. That is why it is appropriate to use this method in the future. Further, the attribute $x_2$ was rationed, and results are presented in table 9.

Table 9 – Results of rationing of attribute $x_2$

| $x$ | $x^*$ |
|---|---|
| 10 | 0,157 |
| 11 | 0,207 |
| 12 | 0,382 |
| 13 | 0,407 |
| 15 | 0,5 |
| 16 | 0,616 |
| 17 | 0,692 |
| 18 | 0,761 |
| 19 | 0,827 |
| 20 | 0,862 |

Based on the conditions of the test example, the attributes $x_1 = 5, x_2 = 25$ . Using the tables 7 and 10, the values of these attributes were determined in a dimensionless form:$x_1^* = 0.33,\ x_2^* = 0.5$. Based on this, the current situation $S_0$ can be written as follows:

$S_0 = \{\ll 0.33/few >/x_1 >, \ll 0.5/enough >/x_2 >\}$.

Now, there is a problem to determine which of the reference situations is closest to the current situation S_0. For this, it was decided to use the Mamdani fuzzy inference algorithm.

The algorithm consists of six main stages:

The first stage is formation of the rule base. Input variables are $x_1$ and $x_2$. Output variable – Situation, that is, as a result of the algorithm execution, we should get one of the possible situations [6].

To solve the problem using the Mamdani algorithm, the following rule base was formed:

Rule 1: IF $x_1$ is “few” AND $x_2$ is “few” THEN Situation = $S_1$

Rule 2: IF $x_1$ is “enough” AND $x_2$ is “enough” THEN Situation = $S_5$

Rule 3: IF $x_1$ is “many” AND $x_2$ is “many” THEN Situation = $S_8$

The second step is fuzzification of input variables. As a result of cluster analysis, membership functions were obtained for each term of the input variables. It means that the input variables are already reduced to fuzziness.

On the third step the degree of belonging of the incoming value to a certain term-set is determined for each rule and the minimum of them is selected using formula (5).

$$c_j = \min\{b_i\}. \tag{5}$$

For this, the membership matrices obtained as a result of clustering can be used, or by substituting the original values of attributes into the corresponding functions obtained as a result of approximation. Performing the calculations, the results were obtained:

$$c_1 = \min\{b_1\} = \min\{\mu_1(x_1); \mu_1(x_2)\} = \\ = \min\{0.6225; 0.0086\} = 0.0086;$$

$$c_2 = \min\{b_2\} = \min\{\mu_2(x_1); \mu_2(x_2)\} = \\ = \min\{0.3384; 1\} = 0.3384;$$

$$c_3 = \min\{b_3\} = \min\{\mu_3(x_1); \mu_3(x_2)\} = \\ = \min\{0.038; 0.0084\} = 0.0084.$$

At the next stage truncated sets were found. The number of truncated sets must match the number of rules. All truncated sets were determined by the formula (6).

$$\mu_i^* = \min\{c_i, \mu_i(y)\}. \tag{6}$$

The truncated set of the first rule takes the form:

$$\mu_1^*(0) = \min\{c_1, \mu_1(0)\} = \min\{0.0086; 0\} = 0;$$

$$\mu_1^*(1) = \min\{c_1, \mu_1(1)\} = \min\{0.0086; 1\} = 0.0086;$$

$$\mu_1^*(2) = \min\{c_1, \mu_1(2)\} = \min\{0.0086; 0\} = 0;$$

…………

$$\mu_1^*(10) = \min\{c_1, \mu_1(10)\} = \min\{0.0086; 0\} = 0.$$

The truncated set of the second rule takes the form:

$$\mu_2^*(0) = \min\{c_2, \mu_2(0)\} = \min\{0.3384; 0\} = 0;$$

…………

$$\mu_2^*(5) = \min\{c_2, \mu_2(5)\} = \min\{0.3384; 1\} = 0.3384;$$

…………

$$\mu_2^*(10) = \min\{c_2, \mu_2(10)\} = \min\{0.3384; 0\} = 0.$$

The truncated set of the third rule takes the form:

$$\mu_3^*(0) = \min\{c_3, \mu_3(0)\} = \min\{0.0084; 0\} = 0;$$

$$\mu_3^*(1) = \min\{c_3, \mu_3(1)\} = \min\{0.0084; 0\} = 0;$$

…………

$$\mu_3^*(10) = \min\{c_3, \mu_3(10)\} = \min\{0.0084; 0\} = 0.$$

In order to find the truncated sets was selected step $h = 1$. To find more accurate sets, the step should be reduced.

Next, a combined output set was constructed. It is the union of all truncated sets and is determined by formula (7) [7].

$$\mu_i^{**} = \max\{\mu_i^*\}. \quad (7)$$

Combined set takes the form:

$$\mu_i^{**}(0) = \max\{\mu_1^*(0), \mu_2^*(0), \mu_3^*(0)\} = \\ = \max\{0; 0; 0;\} = 0;$$

$$\mu_i^{**}(1) = \max\{\mu_1^*(1), \mu_2^*(1), \mu_3^*(1)\} = \\ = \max\{0.0086; 0; 0;\} = 0.0086;$$

$$\mu_i^{**}(2) = \max\{\mu_1^*(2), \mu_2^*(2), \mu_3^*(2)\} = \\ = \max\{0; 0; 0;\} = 0$$

$$\mu_i^{**}(3) = \max\{\mu_1^*(3), \mu_2^*(3), \mu_3^*(3)\} = \\ = \max\{0; 0; 0;\} = 0$$

$$\mu_i^{**}(4) = \max\{\mu_1^*(4), \mu_2^*(4), \mu_3^*(4)\} = \\ = \max\{0; 0; 0;\} = 0$$

$$\mu_i^{**}(5) = \max\{\mu_1^*(5), \mu_2^*(5), \mu_3^*(5)\} = \\ = \max\{0; 0.3384; 0;\} = 0.3384$$

$$\mu_i^{**}(6) = \max\{\mu_1^*(6), \mu_2^*(6), \mu_3^*(6)\} = \\ = \max\{0; 0; 0;\} = 0$$

…………

$$\mu_i^{**}(10) = \max\{\mu_1^*(10), \mu_2^*(10), \mu_3^*(10)\} = \\ = \max\{0; 0; 0;\} = 0.$$

At the last step, a clear value of the output variable was determined, that is, the number of situation which describes the state of the company. To implement defuzzification, it was decided to use the center of maximum method. In the center of the maxima method is the arithmetic average of the elements of the universal set, having the maximum degrees of belonging, formula (8).

$$y = \frac{\sum_{x_j \in G} x_j}{|G|}. \quad (8)$$

where $G$ – set of elements with a maximum degree of belonging;

$\sum_{x_j \in G} x_j$ – sum of elements of a set $G$;

$|G|$ – power of set $G$.

In this case, the membership function has only one maximum, then this coordinate is a clear analog of the fuzzy set. This point has a degree of belonging $\mu^{**}(5) = 0.3384$ and corresponds to the value $y = 5$. Therefore, it can be concluded that the closest to the current situation $S_0$ is the reference situation $S_5$.

The Similar calculations were carried out in the MATLAB environment and the obtained results were obtained. As a result of the application of the Mamdani algorithm in the MATLAB environment, the search for the closest reference situation to the original one was carried out.

According to the values of attributes indicated in the condition of the test example, the value $y = 5$ was obtained. It means, that the reference situation $S_5$ is most similar to the current situation $S_0$. The manual calculations were performed correctly and coincided with the results in the MATLAB environment.

**Conclusions.** The authors considered the problem of assessing the state of the enterprise (for example, an IT company). The problem is presented in the form of two tasks: the aggregation of the initial information and the identification of the state of a complex system.

Formulated problem statements and selected methods for their solution.

To solve the problem of aggregating the source data, fuzzy cluster analysis was used. Namely, the fuzzy *k*-means method. Calculated test case. The obtained numerical result was approximated by analytical membership functions. The solution of the first problem allowed to form fuzzy reference situations. Each reference situation is characterized by an informational granule.

The second problem was solved using the fuzzy logic method. Calculated test case. Using the fuzzy logic method, the current situation was compared with the reference situations. As a result, it was determined which of the reference situations is closest to the current one. This allowed us to determine the assessment of the state of an IT company.

The theoretical and practical results can improve the efficiency of complex system management.

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*Received 01.06.2019*

*Відомості про авторів / Сведения об авторах / About the Authors*


***Голоскоков Олександр Євгенович*** – кандидат технічних наук, доцент, Національний технічний університет «Харківський політехнічний інститут», професор кафедри Програмної інженерії та інформаційних технологій управління; м. Харків, Україна; ORCID: https://orcid.org/0000-0003-1824-6255; e-mail: prof.goloskokov@gmail.com

***Яковенко Артем Анатолійович*** – Національний технічний університет «Харківський політехнічний інститут», студент; м. Харків, Україна; ORCID: https://orcid.org/0000-0002-9246-5889; e-mail: iakovenko25@gmail.com

***Голоскоков Александр Евгеньевич*** – кандидат технических наук, доцент, Национальный технический университет «Харьковский политехнический институт», профессор кафедры Программной инжинерии и информационных технологий управления; г. Харьков, Украина; ORCID: https://orcid.org/0000-0003-1824-6255; e-mail: prof.goloskokov@gmail.com

***Яковенко Артем Анатольевич*** – Национальный технический университет «Харьковский политехнический институт», студент; г. Харьков, Украина; ORCID: https://orcid.org/0000-0002-9246-5889; e-mail: iakovenko25@gmail.com

***Goloskokov Alexander*** – candidate of technical sciences, docent, National technical university «Kharkiv polytechnic institute», Professor of the Department of Software Engineering and Information Technology Management; . Kharkiv, Ukraine; ORCID: https://orcid.org/0000-0003-1824-6255; e-mail: prof.goloskokov@gmail.com

***Yakovenko Artem Anatolievich*** – National technical university «Kharkiv polytechnic institute», student; c. Kharkiv, Ukraine; ORCID: https://orcid.org/0000-0002-9246-5889; e-mail: iakovenko25@gmail.com